ELF

ILLINOIS NATURAL HISTORY SURVEY

Section of Wildlife Research

ELF Communications System Ecological Monitoring Program:
Field Studies of Effects of ELF on Migrating Birds

Subcontract Number E06516-82-C-50015 issued by IIT Research Institute under Prime Contract Number N00039-81-C-0357 from the Department of the Navy Naval Electronic Systems Command

Annual Report

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University of Illinois at Urbana-Champaign
Urbana, IL 61801

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GLOSSARY AND ACRONYMS

<u>A/D Converter</u>: Analog-to-Digital converter. Generates a number whose value corresponds to an analog voltage present on an input line.

<u>A-scope</u>: A fundamental radar display presenting the strength of radar echo vertically and the range horizontally, along the radar beam.

<u>Air Speed</u>: The rate at which a target travels with respect to the air.

<u>Amplitude</u>: In this report, radar echo amplitude is used virtually synonymously with intensity and reflectivity. It is the amount of energy reflected back to the radar from a given target and is a function of the size of the target, the orientation of the target if it is not spherical, and especially of the range of the target.

<u>ASCII</u>: American Standard Code for Information Exchange. A representation of alphanumeric characters as numbers.

<u>Aspect</u>: The direction a radar target is facing relative to the radar. Aspect is commonly measured by examining the amplitude of radar echo returned from a target as the target is rotated around through 360°.

<u>Azimuth</u>: Compass bearing measured from 0 to 360° relative to true north.

<u>Beamwidth</u>: The angle subtended by a radar beam. Specifically, the azimuthal beamwidth is the number of degrees over which the radiated radar energy is at least half that in the center of the beam, where the energy is maximal.

<u>D/A Converter</u>: Digital-to-Analog converter. An output device which generates a voltage corresponding to the value of a number.

<u>Directory</u>: A list of the FILES or RECORDS on a device, along with information as to their length and where they reside on the device.

<u>Disk</u>: A platterlike magnetic mass storage device. The platter, or sometimes the reading head, spins rapidly and the data are arranged in concentric strips around the platter. Any part of the data is accessible in a fraction of a second.

<u>Echo</u>: A wave signal reflected off a target and picked up by an appropriate receiving device.

<u>Elevation</u>: The vertical angle of the radar beam, with the horizon as 0° and the zenith as 90°.

<u>ELF</u>: Extremely Low Frequency.

<u>File</u>: A unit of data storage which is composed of many records or other subunits and which is represented in a directory by a name or other unique code.

Format: An arrangement of data by convention. Formatting data often includes inserting identifying information, scaling or changing radix, arranging into standard-size blocks, etc.

GPG: A 3-cm tracking radar unit operated by the Illinois State Natural History Survey for the purpose of studying flying animals. This unit, an AN/GPG-1, has been modified from a military radar designed to track aircraft in fire-control work.

Ground Clutter: Targets on or near the ground generating unwanted radar echoes. These include topographic features, trees, buildings, ocean waves, automobiles, and other moving or stationary targets.

Ground Speed: The rate at which a target travels with respect to the ground. The vector addition of wind speed and a target's air speed equals the ground speed.

Heading: Angle of travel with respect to the air. It is assumed that the heading is the direction an animal's body is pointed. The heading is one component of velocity relative to the air; air speed is the other component.

IF: Intermediate Frequency.

IITRI: Illinois Institute of Technology Research Institute.

K-value: Integer ranging from 0-9 which indicates the range of disturbance in the earth's ambient magnetic field within a specified time period (3 hours).

Line Printer: An output device which (usually) impacts one entire line of alphanumeric characters at a time on a moving sheet of paper.

Memory: Usually refers to ferrite CORE, SEMICONDUCTER, or sometimes DISK where data and programs are stored for ready access.

Migration Traffic Rate: Rate of migrants passing a point or over a line. Usually expressed in migrants per linear unit of front per unit time.

Minicomputer: A computer which is small in size and cost. It is bigger than a MICROCOMPUTER and substantially bigger than a MICROPROCESSOR, but smaller than a MAINFRAME.

Mist Net: A fine string, large mesh net, rectangular in shape and supported by poles, used to live trap birds for tagging, banding, etc.

Modem: MOdulator-DEModulator. A device used in communications to perform parallel-to-serial conversion and to send data along a phone line or similar channel.

Off-Line: Method of operation in which data are gathered at one time and place and fed into the computer at a later time and different place, usually at the computer's convenience.

On-Line: Method of operation in which the user and/or data-generating or display mechanism communicates directly and often interactively with the computer. On-line has nothing to do with the New York expression "standing on line".

Operating System: A set of compatible programs or routines, often written by the manufacturer of the computer, which governs the running of the computer and may perform such functions as communicating with peripheral devices, allocating portions of core or semiconductor memory to different programs, scheduling jobs, and maintaining organized files on mass storage devices.

Peripheral Equipment: Devices which connect with the CPU. Usually synonymous with I/O devices.

Pulse Length: The length of a brief pulse of radar energy, measured in time (microseconds) or in distance (meters).

Pulse Width: Same as pulse length.

Range: Straight-line distance from the radar to the target. By "range" is usually meant "slant range", not distance over the ground.

Real Time: Responses to a situation are in real time if they occur fast enough to influence the events to which they are responsive.

Shear: In the most common meteorological usage, shear refers to variation in wind velocity with altitude above the ground.

Shorebird: Charadriiform birds; they commonly frequent the seashore and other open habitats and are small-to moderate-sized birds with longish legs and narrow bills. They characteristically fly in densely-packed flocks and include plovers, sandpipers, and similar birds.

Target: Something that generates a radar echo.

Terminal: A peripheral device which is physically separated from its computer. It is a teletype, keyboard-and-display, card reader, or possibly a collection of data acquisition devices which may be connected directly to the computer or via phone lines. Terminals are often serial devices which transmit and receive ASCII code.

Track: (1) A record of an animal's path.
(2) The direction of travel relative to the ground.

UP: Upper Peninsula of Michigan.

VSU: Video Sampling Unit. Equivalent to a sweep-sampling circuit, it takes one sample of the radar IF after each radar pulse. The time delay (range) of the sample is programmable.

Waterfowl: Collective referring to ducks, geese, and swans (members of the order Anseriformes).

Wave Length: The distance between crests of the wave-like electromagnetic energy emitted by microwave radars. Radar wave lengths range from millimeters to a few tens of centimeters. Wave length is inversely proportional to frequency.

Winchester Disk: A non-removable mass storage device for computers.

Wingbeat Signature: The time series of echo amplitude fluctuations of an animal target being tracked by radar.

WTF

ABSTRACT

Progress on the project to study the effects of the ELF antenna system on migrating birds is reported for the 1983 period. The selected radar site, constrained by topography and power requirements, provides an excellent vantage for comparisons of avian migration before-and-after ELF installation and close to vs distant from the antenna. Data collected during 13 nights in fall, 1983 include 751 individual tracks (mostly birds), 38 counts of target density, and 26 records of wingbeat signatures. Possible reactions of birds to a nearby broadcasting tower were also noted. Few waterfowl were recorded during the census period (24 - 30 October). Radio tracking results were limited by low capture rates of birds in Wisconsin. Software utilities have been developed or modified specifically for the collection, handling, and analysis of data from the Upper Peninsula.

SUMMARY

Field studies of possible effects of ELF upon birds migrating near an ELF antenna system or living near it and then departing in the fall were conducted by the Illinois Natural History Survey, a division of the Department of Energy and Natural Resources. Part of the study, censusing waterfowl, was performed at nearby lakes in daytime. However, because the majority of birds migrate at night, it is necessary to use special techniques to monitor possible effects upon bird migration. Techniques employed were tracking and counting birds with the use of a portable radar unit and following individual birds tagged with miniature radio transmitters.

Field work was supported for a 5.5-month period during which time no construction on the Michigan ELF system had ~~yet~~ taken place. The waterfowl census, performed in Michigan in late October when waterfowl on the Great Lakes are still abundant, nevertheless encountered only small numbers of migrant ducks, geese, and swans. The proposed Michigan site is near but not directly within major waterfowl migration routes.

Monitoring with miniature radio transmitters was not successful, partly due to a paucity of birds in the Wisconsin area that could be captured in order to attach the miniature transmitters and partly due to administrative problems. This technique is important because it allows birds to be followed beyond the range at which radar can effectively operate and therefore permits one to distinguish long-term effects from those that may be only temporary.

Radar is recognized as a useful technique for recording the altitude, speed of flight, and numbers of passing migrants. Previous studies in Wisconsin have found varying degrees of effect of ELF radiation upon migrating birds. Monitoring with radar was carried out using a trailer-mounted tracking

radar sited about 500 m from a segment of the ELF antenna right-of-way. Over 700 radar tracks were recorded. Unusually warm weather during early fall, 1983, was associated with lower-than-expected numbers of passing migrants visible on the radar displays, rendering generalizations concerning the normal migration patterns in the Upper Peninsula premature. This first field season indicated that curving paths of migrating birds may be more common in the Upper Peninsula in fall than suspected and that insects as well as birds are commonly found flying above the ELF right-of-way.

SCIENTIFIC BACKGROUND

The NAS Committee (1977) reviewed the evidence for effects of Extremely Low Frequency radiation (ELF) effects on migrating birds and recommended "further research on the basic biology of bird navigation and orientation designed to verify recent highly suggestive experiments and to address the questions noted [in the review]". Several other reviews of this literature have appeared since (Keeton, 1979a, 1979b; Able, 1980; Moore, 1980; Walcott, 1982). The major conclusions of the NAS report are not significantly altered by developments since its publication in 1977. Magnetic sensitivity is well-established in birds which regularly migrate or make homing flights. Laboratory conditioning experiments are rarely successful in revealing this sensitivity, with the exception of Bookman's (1977, 1978) paradigm. Birds seem to use several orientation cues rather than relying on any single cue such as magnetism, although in some birds the magnetic "compass" appears to serve as the cue which is used to align nonmagnetic orientation systems (Wiltschko and Wiltschko, 1978 and papers cited therein). Magnetic cues have a small yet detectable influence on pigeon homing even under sunny skies, when visual mechanisms predominate (reviewed in Keeton, 1979b; Visalberghi and Alleva, 1979). Much remains to be learned about the interaction of different sensory channels in avian orientation. The remainder of this section will address issues on which new findings have emerged since the NAS report.

<u>Low-level magnetic fields appear to affect normal avian orientation</u>. Experiments and observations by Southern (1975), Larkin and Sutherland (1977) and Williams and Williams (1978) agreed that operation of the Wisconsin Test Facility sometimes affected the direction taken by birds, strongly suggesting that the birds therefore could sense the electromagnetic fields produced by the

transmitter. In a previous report, Keeton et al. (1974) had found that normally-occurring slight fluctuations in the earth's magnetic field (K-values) affect the departure bearings taken by homing pigeons. Therefore, it was suggested that birds could sense weak magnetic fields, on the order of one or a few percent of the earth's field, and that both AC and DC fields affected avian orientation. Although other reports found little or no effect of fluctuations in K-values on migratory direction (Able, 1974; Richardson, 1974, 1976) or speed (Larkin and Thompson, 1980), evidence for effects of low-level magnetic fields has continued to accumulate. Schreiber and Rossi (1978) reported that speed of homing was negatively correlated with solar activity (and therefore with magnetic disturbance). Moore (1977) found that free-flying passerine migrants responded to increased K-values, increasing the variability of flight directions. T. S. Larkin and Keeton (1976) found that magnets masked the effect of K-values on pigeon homing, supporting the direct effect of magnetic disturbance as opposed to an indirect effect via some other hidden variable.

Experiments by Walcott and colleagues (Walcott, 1978, 1980, 1982) demonstrate that naturally-occurring magnetic anomalies in the earth's crust affect the paths taken by homing pigeons; these experiments have been corroborated and the nature of the influence of anomalies investigated by investigations in Europe (Frei, 1982; Kiepenheuer, 1982). Thus, small temporal and spatial changes in the DC field of the earth appear to play a part in normal orientation of at least some birds; it is not known whether effects of AC fields at the Wisconsin site are mediated by the same physiological mechanisms responsible for DC sensitivity.

Structures with magnetic activity are present in birds, honeybees, and other animals; the structures are obviously candidates for "the magnetic

receptor". Cells containing small, seemingly well-organized magnetic structures have been reported in the abdomens of bees (Gould et al. 1978), in the heads and necks of pigeons (Walcott, et al., 1979; Presti and Pettigrew, 1980; Walcott and Walcott, 1982), in the heads of Pacific dolphins (Zoeger et al., 1981), and in the skulls of small rodents (Mather, 1982), and humans (Baker, 1982). The location of the magnetic material is variable or imprecisely determined; its function has not been demonstrated. Semm (1982) reports single-cell evoked responses to magnetic stimuli in pigeon pineal organ. No sensitivity levels nor behavioral thresholds have been demonstrated thus far in any tissue or animal. Nevertheless, the outlook is promising for discovering a physiological substrate for magnetic sensitivity (at least to DC fields).

The impact of ELF upon migrating birds is still an open question. A review article by Grissett (1980) minimizes the potential impact of ELF upon migrating birds, implying that the recommendations of the NAS Committee (1977, p. 242) regarding further work on this subject had been completely followed. The article relies on the final project report of the continuation of Williams and Williams' (1978) study using the low-power Ornithar radar. It overlooks the limitations of the Ornithar. The unit often cannot distinguish XY turns from altitude changes (Cohen and Williams, 1980). The majority of migrants cannot be detected by the unit because they pass above its maximum range of 1000 feet (300 m). Many or most of the responses to antenna state found by Larkin and Sutherland (1977) could not have been observed with the Ornithar. The Williams' (1978) simulation of migration based on a fixed-compass model with ELF perturbations lacks empirical support; we do not know the mechanism of goal-directed orientation of migrating birds over land.

GENERAL EXPERIMENTAL DESIGN

Field procedures and data analysis have been designed to assess several potential impacts of the ELF antenna system on migrating birds (Table 1). Altered density (numbers) of migrants passing over a functioning ELF antenna would automatically signal potentially serious impact, because of the implied interference with the success of the migratory journey. If effects are found, follow-up investigations would have to ascertain whether individual birds suffered negative effects, or whether effects would be temporary, the birds merely detouring around the system. Studies of pigeons near magnetic anomalies and wearing permanent magnets demonstrate the adaptability of the magnetic orientation system of birds (Keeton et al., 1974; Walcott, 1978, 1982). The techniques used in this investigation provide measures of density of migration.

Disorientation of birds in ELF fields, previously reported by Southern (1975) and by Larkin and Sutherland (1977), and the effects of growing up in an altered magnetic field (Wiltschko, et al., 1983; Bingman, 1983; Alerstam and Hoegstedt et al., 1983) might be temporary or long-term. In assessment of ELF impacts, discrimination between temporary and long-term alterations in course is essential. Short-range techniques such as the ceilometer and low-power radars cannot make this discrimination. The tracking radar technique proposed in the present study allows a single bird to be followed for 3 km or more, with favorable siting. This range permits the investigator to discriminate temporary course changes from longer-lasting ones within the antenna array. The radio tracking technique allows recording of the direction of a bird out to a range of about 150 km; this technique will allow a bird to be released from within the Michigan antenna array and followed as it leaves the array toward

Table 1. Variables important in the Radar Tracking Task.

Variables that might show effects of ELF (dependent variables)

- Target density
- Altitude distribution
- Straightness and levelness of tracks
- Orientation of tracks
- Speed of flight

Variables determining or influencing possible ELF effects

- Target identity (including size and wingbeat signature)
- Geographic location of tracks (including 2- and 3-dimensional distance from antenna)
- Before/after installation of antenna
- Wind speed and direction
- Time of night
- Ambient magnetic environment (including magnetic topography, K-values, and ELF radiation not due to Project ELF)

surrounding habitat. If the birds are reoriented or disoriented by the ELF fields, it will be possible to ascertain whether they resume a normal flight direction as they leave the fields. No other available method permits this kind of discrimination between temporary and chronic effects.

The tracking radar permits unambiguous determination of flight altitude independent of the path taken by the target over the ground. In tracking mode, the radar allows changes in altitude to be recorded; such changes were among effects found in the earlier ELF impact work. In VSU mode (Appendix 2), automatic distributions of birds' flight altitude are generated; distributions within and without the ELF fields can be compared statistically.

The VSU and radio tracking techniques allow the departure times of, respectively, the overall migrant population and individual birds to be measured within seconds or minutes. The VSU, when used at 15 degrees elevation, can detect birds as low as 50 m.

Originally, five techniques were to be used to investigate possible effects of ELF upon migrating birds. The original design evolved, partly at the suggestion of IITRI, partly because of experience in the first field season, into a structure consisting of four tasks:

(1) Radar Tracking
(2) Radio Tracking
(3) Waterfowl Survey
(4) Ambient Monitoring

CHRONOLOGY

Research originally scheduled over a 14-month period was conducted in 5 months because of funding delays (Appendix 1). One field season instead of two was spent on the radio tracking task (see below). Other tasks were completed. No measurement of AC or DC electromagnetic fields was made in 1983 at the study sites.

ACCOMPLISHMENTS IN STUDY TASKS

Radar Tracking

The NAS committee (1977, p. 53) recommended "a baseline study using radar tracking of bird navigational patterns among migrating species in the vicinity of the proposed installation, to be continued when the ELF (antenna) is in operation". The committee discounted the possibility that the radar technique itself influenced flying birds (p. 239). Direct effects of the ELF on the tracking radar were not observed in the earlier study (Larkin and Sutherland, 1977); because the birds' reactions occurred in Cartesian coordinates and the radar operates in polar coordinates, such direct effects on the radar were ruled out completely.

Initial radar site selection took place in late July 1983 in the Upper Peninsula of Michigan. However, information obtained at that time regarding land ownership was incorrect. The search for an alternate site and the installation of power delayed work approximately one week after arrival in mid-August.

Site selection was constrained by a suite of requirements: proximity to the ELF antenna right-of-way; vantage over the ELF right-of-way and over other land distant from the ELF right-of-way; accessibility by road; location on land unlikely to be disturbed during the study; freedom from nearby human activity such as a heavily-travelled road, town, and so on; and availability of power. A location in the Upper Peninsula was found that met these requirements, and the radar was sited there. Towers provide some obstruction, but other aspects of the site are nearly optimal.

The site is located in typical upland habitat used for commercial wood production. Rolling terrain with no prominent topographic features surrounds

the radar site and nearby antenna right-of-way. Vegetation is almost entirely monotypic stands of Jack Pine from 0 to 30 years of age in different land holdings. Aside from a 5-ha lake about 1 km away, only small streams flow through the land in the purview of the tracking radar.

Field data were collected from 26 August to 09 September 1983 (actually until 0730 on 10 September, Table 2). Weather during this period was atypical and, generally, unfavorable for large scale migrations. Winds toward the south, the most favorable for fall migration, occurred on only one night. Some nights with favorable wind also had continuous rain. Recorded densities of migrants ranged from 2-60 birds per minute passing through the lowest 1725 m of the atmosphere in the beam of the radar. Actual Migration Traffic Rates, computed from the VSU data, are being calculated based upon the observed target size distributions and other parameters.

Problems occurred with the azimuth data collection circuits and with the target selector. These two problems occurred following a storm which also left us without electrical power for the early part of one evening session; we were gathering data a very short time after power was restored.

A total of 2 megabytes of data were collected. This included 26 records of wingbeat signatures, 38 counts of target densities totalling several thousand birds, and 751 individual tracks, the majority of which are birds.

Data analysis is ahead of schedule. Running of the first three programs of the data reduction process has been completed (Appendix 3). Other support software that has been developed or modified includes:

1. utility for transferring data files from the field computer to the lab computer;
2. translation of wingbeat frequencies from binary to ASCII formats;
3. display of wingbeat frequencies (Figs. 1 and 2);

Table 2. Overall summary of radar data collected in the Upper Peninsula in 1983.

Date 1983	Number of tracks Insects	Birds	Balloons	Wind direction toward	% cloud cover	Targets per minute
26 Aug	26	7	1	N	30-80	--
27	12	47	2	airs	0-10	3-15
28	17	34	1	none or airs	0	2-5
29	25	26	1	airs	0-70	4-18
30	21	19	2	S	0	13-60
31	35	62	3	airs	0-10	3-6
1 Sept	4	4	0	N to NE	0	3
3	19	27	1	S	90-100	8
4	10	43	2	N or airs	85-100	16
5	6	9	0	N	100 (fog)	20-30
6	11	52	0	E	0	11-30
8	4	4	0	E	5-20	--
9	28	87	3	variable	0-100	3-14

4. plotting of radar ground clutter;

5. summary of target size and variability;

6. display of target standard deviations;

7. on-line program that collects ground clutter information and produces real-time plots for more efficient data gathering in the future;

8. off-line graphical track editing program.

Planned research in Wisconsin could not be conducted because of Navy commitments to use the WTF for Navy operations. Therefore, IITRI and the investigators decided to change plans and mount an effort in the field in Michigan instead of WTF. Protocols designed for WTF will not be used and replication of Larkin and Sutherland (1977) will not be feasible.

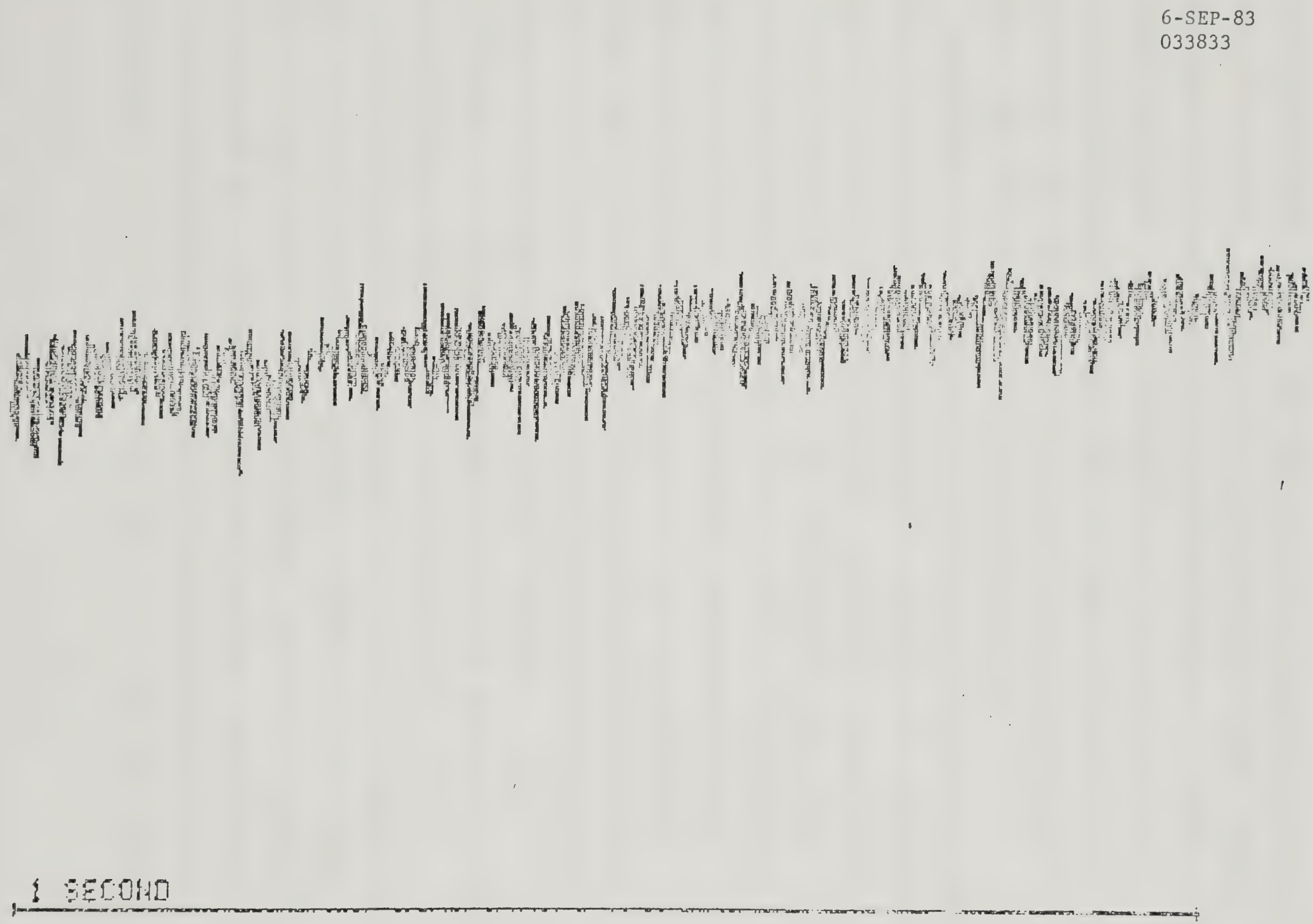
Based on initial field work, we can now revise the scientific protocols for the radar part of the bird migration study. We are located south of an east-west leg of the antenna system right-of-way. Because of the geographical situation, birds cannot approach the radar (except from about 100°) without flying over part of the surveyed ELF antenna right-of-way. Thus, our central location provides before-and-after comparison but does not allow tracking of birds at a great distance from the ELF antenna.

For the before-and-after comparison, we are gathering data on departure times (measuring the onset of nocturnal migration), on straightness and constancy of altitude of long bird tracks, and on the numbers of targets passing over the area per unit time. In support of these data, we are gathering data to assess the variability in number, altitude, and orientation of bird targets over the site.

If one assumes that increasing distance from a transmitting ELF acts to diminish its potential effects, then this relationship may be exploited to advantage. We now have a radar site that allows us to obtain tracks of birds

Figure 1. Echo time series (wingbeat signature record) of a "birdlike" target.

Figure 2. Echo time series (wingbeat signature record) of a "non-birdlike" (insect) target. Flocks of several or more birds might also generate a time series as steady as this record. Vertical scale is the same as Figure 1.



high over the antenna right-of-way (up to about 2 km AGL) as well as very low over it (below 200 m). Also, we can track birds at a distance from the antenna right-of-way laterally, as well as tracking birds directly above it. We have been concentrating on obtaining very long records of the paths of individual migrants (up to about 4 minutes in duration) that allow comparison of the straightness and levelness of targets in different spatial proximity to the antenna. Many such tracks cross the antenna and allow us to look for spatial effects within different parts of the journey of a single bird.

We suppose that typical post-cold front fall migration will produce rather tighter clumping in the directions assumed by the animals than we have thus far observed (Richardson, 1982). If and when we can predict the probable path of a bird during more typical migration, it should be possible to set up rigid protocols (for instance, of the ABABAB variety) to track birds passing along specific routes. Thus far we have been forced by the weather to remain opportunistic. The results will be less amenable to simple statistical analysis, but will nevertheless provide quantified and statistically testable data (see below). In no case will the data be subject to bias, because the radar unit operates automatically once a track is initiated.

Presence of the Aurora Borealis means that it will be imperative to obtain records of K-values and use them in analyzing the data.

Possible effects of two nearby broadcast towers are being investigated to permit estimation of their importance as confounding factors. This is being done while taking long tracks, as discussed above. Occasionally we track a bird whose path takes it directly toward or near one of the towers. Analysis will permit us to name a distance, angular or linear, constituting a threshold for avoidance of or attraction toward the towers. Birds whose paths exceed

this distance from the towers can then be said to be unaffected by them and thus not subject to confounding. This work needs to be conducted on moonlit, dark, and cloudy, as well as clear nights because these variables are known to be important to birds reacting to lights. Age and other factors may also influence effects of towers (Dunn and Nol, 1980).

Following nights with fog or low cloud and heavy or moderately heavy migration, we shall look for tower-killed migrants below the guy wires to the towers. This will provide an unexpected opportunity to learn something about the species composition of migration exactly at the time and place of the study.

Radio Tracking

The University of Wisconsin had considerable difficulty in finalizing a subcontract. This delayed signing of the subcontract until after useful radio tracking work could be initiated in the fall of 1983.

In an effort to bring this task back on schedule, we developed and submitted to IITRI a plan to take on this task at the Illinois Natural History Survey. The report from the University of Wisconsin (Appendix 4) summarizes their work up until this time. Because no further work on radiotracking will be conducted under this subcontract, detailed review of our previous plans to perform further radio tracking is inappropriate.

Waterfowl Survey

The Illinois Natural History Survey assumed this task from the University of Wisconsin. An experienced field investigator was dispatched to the ELF site on 24 October, immediately after telephone approval. As evident from the field

report (Appendix 5) few waterfowl are present on the lakes in the UP as late as late October. Contacts with biologists from Michigan Department of Natural Resources and Seney National Wildlife Refuge and also local birding enthusiasts indicate:

(1) peak numbers of waterfowl are present from 1-10 October;

(2) few waterfowl are located on the small lakes as late as 24 October;

(3) some mallards, black ducks, and mergansers nest in the small lakes while most others nest in the larger lakes such as Seney NWR.

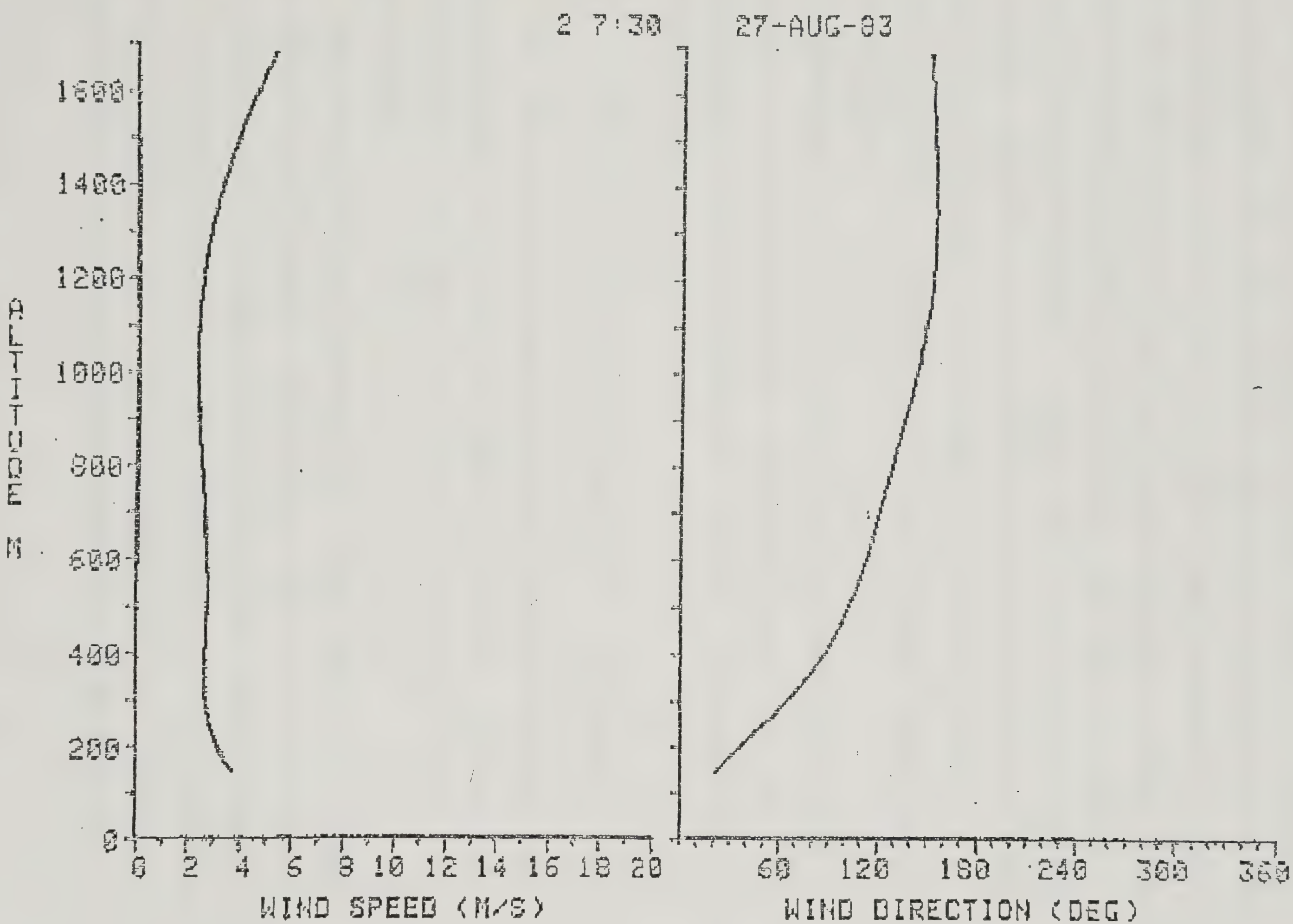
This Task also will not be performed under our Subcontract next year.

Ambient Monitoring

This Task consists of monitoring local weather conditions apt to have an effect upon bird migration in the region and in obtaining data files from other sources in order to look for correlations.

We measure local winds using the technique of tracking radar targets suspended from helium-filled balloons. As the balloons ascend, they are passively transported by the wind in the XY plane, giving an accurate picture of the wind at all altitudes of interest. These wind data are taken at the location of the radar studies and balloons are released at intervals during a data-gathering session, so that winds can be accurately estimated for the time, geographical location, and altitude of each bird track recorded. Off-line programs fit polynomial equations to the X and Y coordinates of the wind vector as a function of altitude, generating wind profiles such as shown in Figure 3. The method of polynomial fitting is being reworked mathematically in order to improve the performance of the algorithm at low and high altitudes.

Figure 3. Vertical wind profile taken with a radar-tracked helium-filled balloon.



Supplementary to the balloon-tracking method of gathering data about the wind was proposed a stationary wind-vane and anemometer to record winds in the surface boundary layer at the radar site. Such a local wind-measuring station has proven most useful to us in previous studies for signalling changes in the wind and therefore providing a timely indication that another balloon-borne radar target should be launched. Funding in 1983 was not received early enough to complete construction of a wind-measuring instrument in time for the 1983 field season in the Upper Peninsula; however, the device has now been constructed and will be field-tested in Illinois in time for the 1984 data collection period.

Because only one night in 1983 had favorable conditions for migration, correlations of migration parameters with K-values, cloud ceilings, and synoptic weather conditions is premature at this point. These aspects of the radar study will be performed in 1984.

PLANNED STATISTICAL ANALYSIS AND SELECTION OF CONTROL GROUPS

This section is written under the assumption that the ELF array will be absent or nonoperative during a Before period, and operating continuously in one mode during an After period, rather than under the control of the experimenters.

We received definitive information about the exact geographical siting of the ELF antenna only in January 1984 and thus have not been able to determine the location of our radar targets relative to the eventual antenna system. Thus, the present section outlines plans for dealing with our data rather than techniques employed in 1983. However, the methods, and in many cases the computer programs, for performing these analyses have been used in previous

publications (e.g., Larkin and Sutherland, 1977; Larkin and Thompson, 1980). It is premature to state the individual statistical test to be used in each analysis; we favor nonparametric statistics when possible (Siegel, 1956) and shall follow Batschelet (1981) for analysis of circular distributions.

Counts of the numbers of migrants flying over the antenna system before and after installation can reveal gross differences. Such counts in fall will be affected by synoptic weather variables (Richardson, 1978), local weather and cloud conditions, productivity in the breeding areas, and the geographical situation in the Upper Peninsula, all factors not under our control. In addition, the unexpected presence of substantial numbers of insect targets in the Upper Peninsula in fall 1983 suggests that overall target counts will have to be corrected for non-bird targets. Before-vs-After comparisons of numbers of migrants flying over the antenna system should be made in at least two ways: (1) matching individual nights or portions of nights in the Before and the After period, and (2) comparing the nights with maximum recorded bird densities in the Before period with those in the After period. Separate analyses should be conducted for all birds passing over the radar and for only those birds in the lowest altitude strata.

Altitude distributions of migrants passing over the antenna might reveal either avoidance of the antenna system in a vertical direction (landing or rising upon encountering the edge of the antenna system) or disorientation to the extent that the numbers of low-altitude migrants (close to the antenna) would be changed. For this analysis, histograms of altitude for individual VSU runs will be converted to frequency distributions and compared for the Before and the After periods.

Disorientation of birds in ELF fields was found by Larkin and Sutherland (1977) and presence of nonlinear or curving radar tracks can be expected to be the most sensitive indication of possible effects of the Michigan ELF system. We have here the advantage of an analysis procedure that has been tried and proven (in a within-night comparative design). Therefore, emphasis in the present monitoring program should be placed upon improving the techniques of the earlier study and in adapting them to a Before-vs-After design. "Non linearities" will be used to designate radar tracks or portions of radar tracks that depart from a straight line in the XY plane. (Including the Z axis is easily accomplished and will not be discussed here for reasons of clarity.)

We can expect about four classes of nonlinearities:

(a) Switches from one radar target to another nearby one. Such "mistakes" on the part of the radar's automatic tracking apparatus are more frequent on nights with many targets present than on nights with only a few. They can usually, but not always, be detected by the radar operator and entered on the handwritten field notes. Most undetected switches can be detected from the stored radar tracks and the graphic editing program allows the data to be split into two separate files during editing of the data.

(b) Artifacts of the data collection circuits. These take the form of either abrupt or gradual changes in one polar coordinate. Because the birds' flight takes place in Cartesian coordinates, polar coordinate artifacts introduce nonlinearities. These are often rectified by recalibrating the radar in the field. Equipment to avoid such artifacts is not available for the monitoring program.

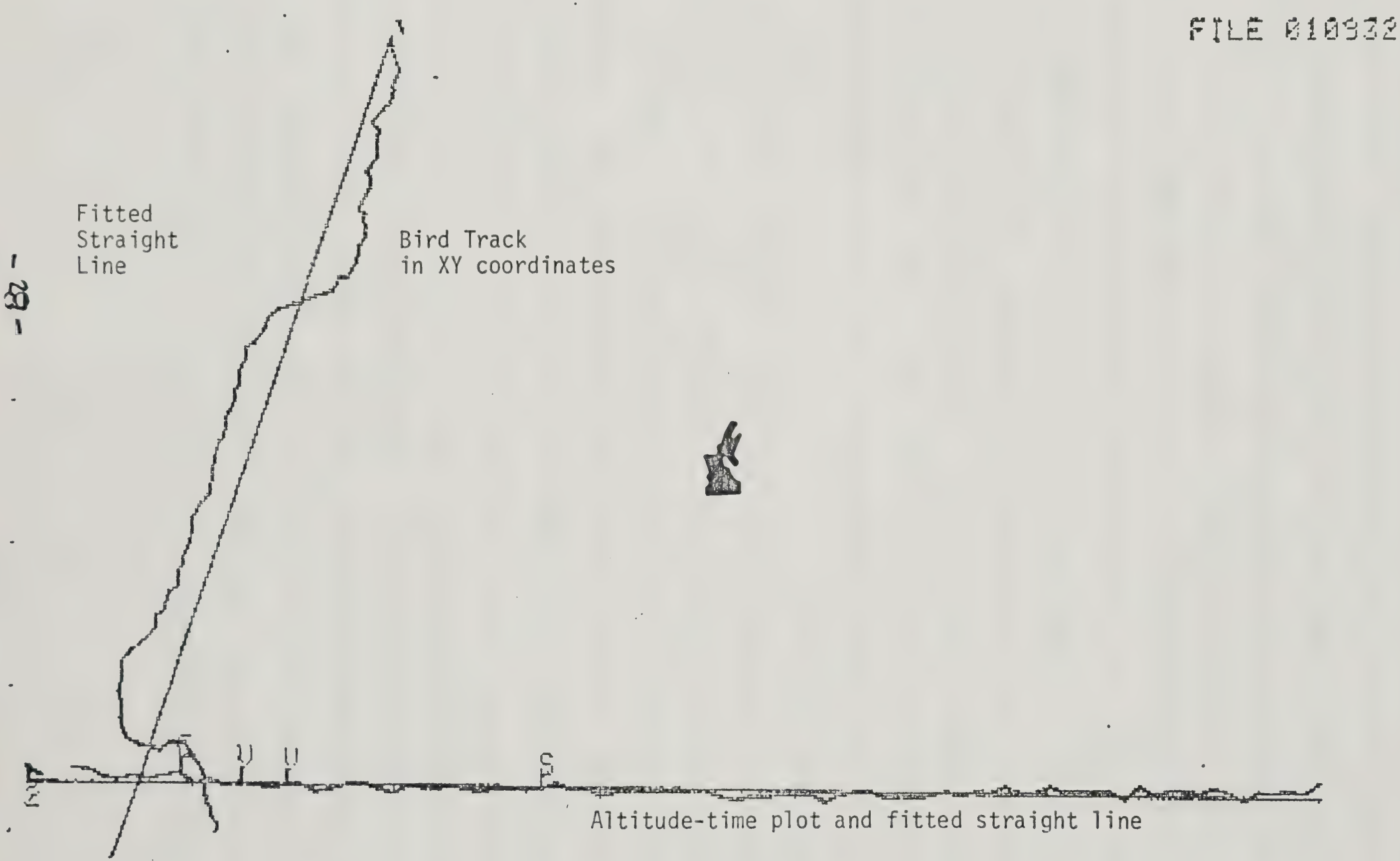
The artifacts often occur at specific ranges or azimuths and thus often can be spotted during the editing procedure.

(c) Continuous curves. Radar tracks are sometimes collected in which the bird changes direction during most or all of the time it is being tracked, either in a series of sharp turns or in one long gradual one (e.g., Fig. 5).

(d) Abrupt curves. A straight track in XY coordinates can suddenly change direction or speed, then can either maintain the new orientation or resume the former flight path. These nonlinearities were encountered in the earlier study at the WTF.

Graphic editing of the radar tracks is performed off-line by an editor without regard to external conditions. In addition, the display does not indicate the altitude of the radar track, so that the editor does not see if a bird is 200 m or 2 km above the antenna array (Fig. 4). During editing, artifacts and switches are first removed from a track. Then straight lines are fitted to the XYZ radar tracks from the beginning of the track up to the place, if any, where a nonlinearity occurs (the onset). If no linear portion is evident at the beginning of a track, no line fitting is done. Thus, the position in four coordinates (X,Y,Z, time) of onset of each abrupt nonlinearity is located for each track in the stored data. If doubts are voiced about the objectivity of the editing procedure, we intend to re-edit selected nights of radar tracking data with the coordinates rotated about the radar by a different random angle for each radar track, thus making it impossible for the editor to tell the direction of the track or the position of the track relative to the ELF array.

Figure 4. Nonlinear bird track of the kind characteristic of many nights of migration activity in the Upper Peninsula.



Analysis for disorientation of radar tracks will take several forms. Directions of migration (headings and air speeds) can be compared directly between the Before and After conditions using standard statistical tests on the fitted straight segments of tracks (Larkin and Thompson, 1980). Continuous nonlinearities can be analyzed by fitting straight lines to the entire radar tracks and comparing distributions of the Standard Error of the linear fits. Abrupt nonlinearities, identified by their onset as described above, can be analyzed using their position relative to the antenna leg (north vs south or before vs after the the bird passes over the antenna leg), their geographical position on a map of the study area, and their occurrence in tracks or different altitudes, directions, etc. Individual tracks in the After period will be matched with control tracks in the Before period in altitude, air speed, and wind conditions.

In the case of abrupt nonlinearities, it will be possible to conduct an analysis comparing tracks within a single night. This comparison will be analogous to studies inside-vs-outside the antenna system being conducted in other aspects of the Ecological Monitoring Program. The procedure will be as follows: Onset of nonlinearities will be identified as described above. Then a control track for each track with a nonlinearity will be selected using, first, a criterion of similarity in altitude, then the closest track in time to the nonlinear track that is as long in duration as the linear portion of the nonlinear track before the onset of the nonlinearity. The XYZ distance from the nearest antenna segment and other parameters can then be compared statistically in order to test the hypothesis that birds flying near an energized ELF antenna are most likely to be disoriented. Of course, the same analysis can be performed on the data from the Before period in order to check

the matching procedure. This analysis assumes that ELF effects diminish with distance (up to approximately the 2-3 km range of the radar unit).

The sensitivity of the tests for nonlinearities will be checked by investigating birds encountering one of the broadcast towers. Such birds are expected to change course upon encountering a large, illuminated steel structure in their path, and we therefore expect to be able to detect a geographical region of increased nonlinearities centered on the broadcast towers. This effect will be weather-dependent, as discussed above.

The above analyses for nonlinearities require that birds be tracked at varying distances from the ELF antenna system during each night's data collection and that the tracks be long in duration. These requirements were largely met in the 1983 season.

Acknowledgments: The preparation of this report benefitted from the comments and criticisms of P. Bartels, A. Lednor, W. J. Richardson, and R. Szafoni.

CONCLUSIONS

We have made the following qualitative observations regarding bird migration over the proposed ELF antenna right-of-way:

- Bird movements are light or nonexistent in daytime, as is common at inland locations, and increase dramatically at dusk.
- Most birds fly straight and level, although the proportion of targets that climb, drop, or turn has been greater than in other work with this radar unit (Fig. 4). This generalization, if sustained in analysis of the results, could be due to the unusual weather conditions, to local or general magnetic effects (Aurora Borealis has

been seen during the study), or to other factors. Some targets have flown such convoluted paths that we suspect they are not migrating birds, but rather gulls, bats, or other kinds of targets.

- Again, probably due to unfavorable weather, directions of travel have been quite variable, both within a night and between nights.
- Low-flying birds, important for assessment of possible ELF effects, have been common enough. When possible, we have concentrated efforts on these birds close over the antenna right-of-way.
- Movements have been studied both on cloudy and on clear nights. Visibility of sunset and of celestial objects is known to be important to migrating birds.
- We have not yet seen a lull or gap in southward migration due to the area of Lake Superior to our north. If present, such a gap should appear in the bird counts obtained by the Video Sampling Unit. We expect to produce better evidence on this point when and if cold fronts penetrate the area.
- Insect-like targets are common in this area (Fig. 5). Their numbers have exceeded those of bird targets on some nights. They appear at a wide range of altitudes and provide problems for the measurement of densities of bird targets. It seems that ELF effects on these numerous and mobile animals might be appreciable, especially if they should become disoriented and alight near an ELF antenna.

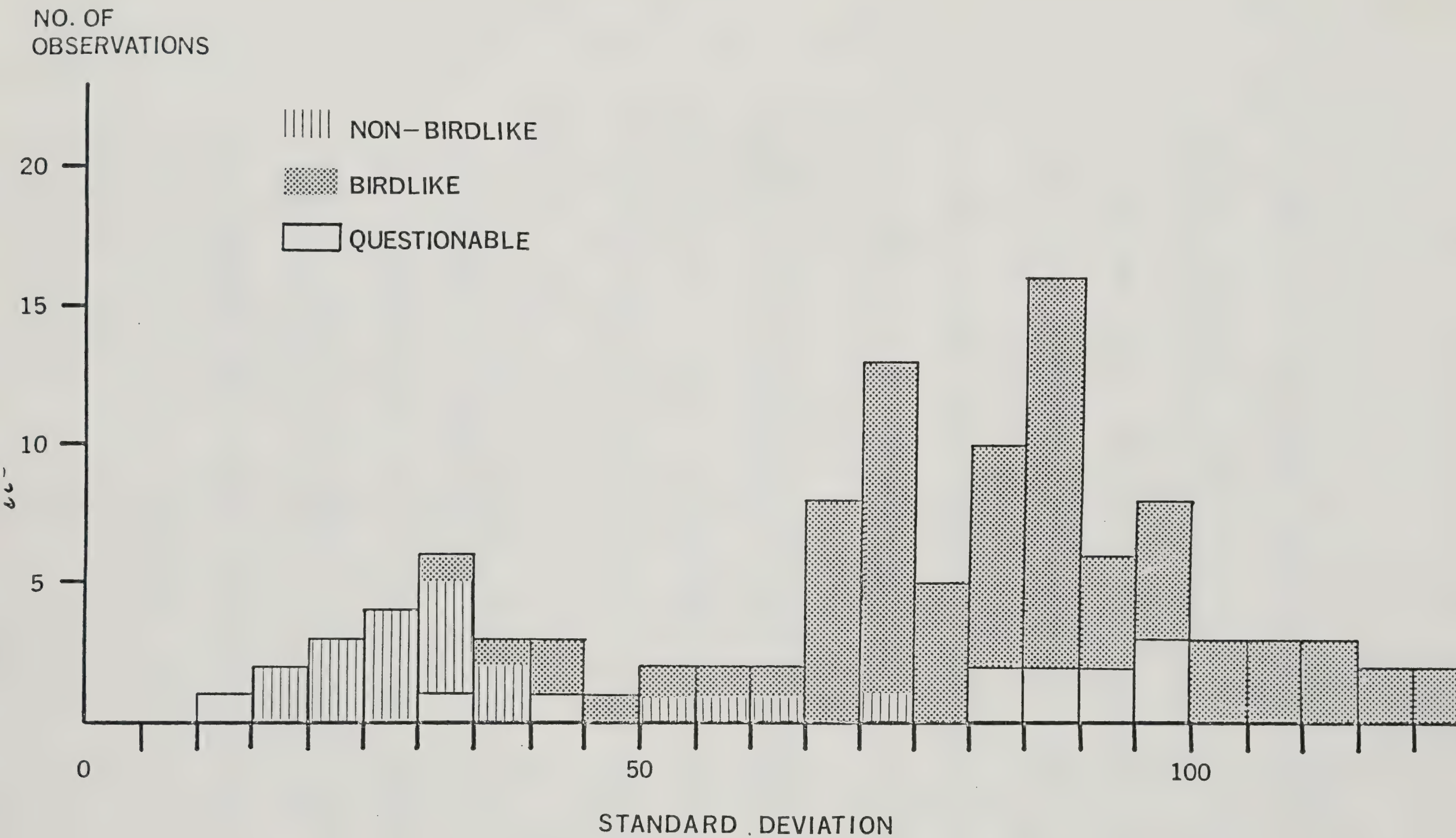


Figure 5. Histogram of standard deviations of echoes of tracked radar targets over Marquette County, Michigan on 9 September 1983. The targets are separated into those targets that appeared to be birds to the radar operator observing the A-scope (shaded), those that were steady without apparent wingbeats (striped), and a few targets that were ambiguous or for which no judgement was recorded. Standard deviations are given in arbitrary units that approximate millivolts of receiver video. The lowest values of standard deviation indicate the approximate noise level of the receiver at moderate ranges.

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Illinois Natural History Survey

Appendix 1

Chronology of First Year: Migrating Birds

April, 1982	-Original proposal submitted
September, 1982 April, 1983	-Revised proposals submitted
February, 1983	-2 months' start-up funding approved
May, 1983	-Radio tracking field study conducted in Wisconsin
June, 1983	-Subcontract issued -Field work shifted to Michigan at the suggestion of IITRI
July, 1983	-Reconnaisance trip to Michigan
August-September, 1983	-Radar tracking field study conducted in Michigan
September, 1983	-University of Wisconsin withdrew from project
October, 1983	-Waterfowl survey conducted in Michigan
November, 1983	-One-month no-cost extension issued for the subcontract -Instructions issued concerning content of Annual Report

Appendix 2

General Description of the Illinois Natural History Survey Tracking Radar Unit

The unit is a surplus AN/GPG-1 military tracker that has been modified for use in the study of flying animals. It is portable in that it is mounted on a newly-built trailer with a combined gross weight of about 2,500 kg. Tracking is of the classical nutating-scan type (specifications are given in Table A3). The effective range for passerine bird targets is from just over 100 m minimum to 2000-3000 m maximum. Individual insects (Cabbage Looper Moths) have been tracked at a range of 1,100 m. Mounted on the trailer with the radar is a weatherproof cabin containing a dedicated minicomputer and other instruments used in calibration and data collection.

When used in tracking mode, the radar operator selects an individual target by observing the A-scope display while manually scanning the antenna in azimuth or elevation. The operator then manually marks the range of the target selected and operates a switch to start the radar autotracking. While autotracking, the radar follows the target being tracked without human intervention; if a larger target crosses near to the target being tracked, the radar may switch to tracking this new target. The target is followed in the three coordinates of azimuth, elevation, and range until the radar switches to a stronger target, the echo from the target being tracked becomes too weak, or the human operator intervenes. A spotlight coaxial with the radar antenna can illuminate the target being tracked and binoculars can then be used to identify nocturnal targets when they are at close enough range.

During tracking, the minicomputer automatically samples the antenna position and range of the target being tracked, converts these values into Cartesian coordinates with the radar at the origin, and stores the information

at a programmable rate on disk. Each radar track is stored as one file, including identifier information and records of events that may have occurred during the progress of the track. One 1-4 sec epoch of target amplitude data can be displayed on-line and stored in a separate signature file. Special modes of operation are available for tracking balloon targets (to obtain wind information) and for calibrating the antenna position circuits.

In addition to long-distance tracking of individual birds, the radar apparatus can also operate in a stationary beam mode in conjunction with a Video Sampling Unit (VSU). The VSU is presently a one-of-a-kind instrument developed by the investigator. Its operation is described in two publications (Larkin and Eisenberg, 1978; Larkin, 1982). It allows objective monitoring of the density and altitude and time distributions of migrating birds, providing data which are uniquely quantitative and free from bias, for the determination of ELF effects. Wingbeat signatures during tracking are monitored by techniques under development.

When used in stationary-beam mode, only the VSU is used to collect data from the radar. The radar antenna is pointed in a certain direction (often vertically) and a computer pattern-recognition program is run to recognize and store records of individual targets passing through the radar beam. Rate of passage is dependent upon altitude, echo amplitude, and speed relative to the ground of each target; the pattern-recognition program takes these variables into account in setting thresholds for the recording of migratory activity. The resulting data (see Fig. A6) can be used in calculating Migration Traffic Rates, altitude distributions, and time profiles of migration during a period of observation.

Table A3. Specifications, Illinois Natural History Survey Tracking Radar.

Type: AN/GPG-1 (AN/MPQ-29) nutating-scan tracker, trailer-mounted

Modes of use: autotracking, stationary-beam (search mode disabled)

Transmitting system
- Frequency: nominal 8850 MHZ (X-band)
- Peak power: 40 kW
- Pulse repetition frequency: nominal 3500 Hz. (variable)
- Source of RF power: Magnetron type 2J51
- Pulse duration: nominal 0.25 microsecond (75 m)

RF and receiving systems
- Antenna: Paraboloid, 76 cm diameter
- Feed: Cutler type
- Beam: 3 degree, conical
- Nutation: nominal 30 Hz, 3 degree conical
- Receiver: Superheterodyne, using 2K25 Klystron as local oscillator
- Intermediate frequency: 30 MHz

Coverage
- Azimuth: 360 degrees
- Elevation: -11.25 to +85 degrees, nominal
- Range: minimum 100 m (ideal clutter conditions), maximum 20 km

Data outputs
- For target acquisition: A-scope and J-scope
- Antenna position and range: digitized by minicomputer (10 bits)
- Target size and signature: digital output from Video Sampling Unit (10 bits)
- Event recording: via event logic and pushbuttons (12 channels)
- Ancillary data: Wind speed and direction, date, time
- Data storage: 8-inch floppy diskettes (file-structured ASCII)
- Tracking data: XYZ position sampled at 0.5-10 Hz, 1 m precision
- Wingbeat signature data: 1-2 second epochs sampled at nominal 350 Hz
- Target density data: target passage through beam recorded within a range window of 225-1725 m
- Real-time computer displays: X-Y, altitude-time, echo amplitude-time, range histogram

Power and physical
- Frequency: 60 Hz
- Power: 4 to 7 kW
- Mass, including trailer and instruments: about 3,000 kg
- Trailer: 579 cm long X 244 cm wide X ca 270 cm high

Ancillary equipment
- Target selector for acquiring targets visually (tripod-mounted)
- Wind vane and anemometer for canopy-level wind measurement (pole-mounted)
- Tracking telescope for observing target (trailer-mounted)

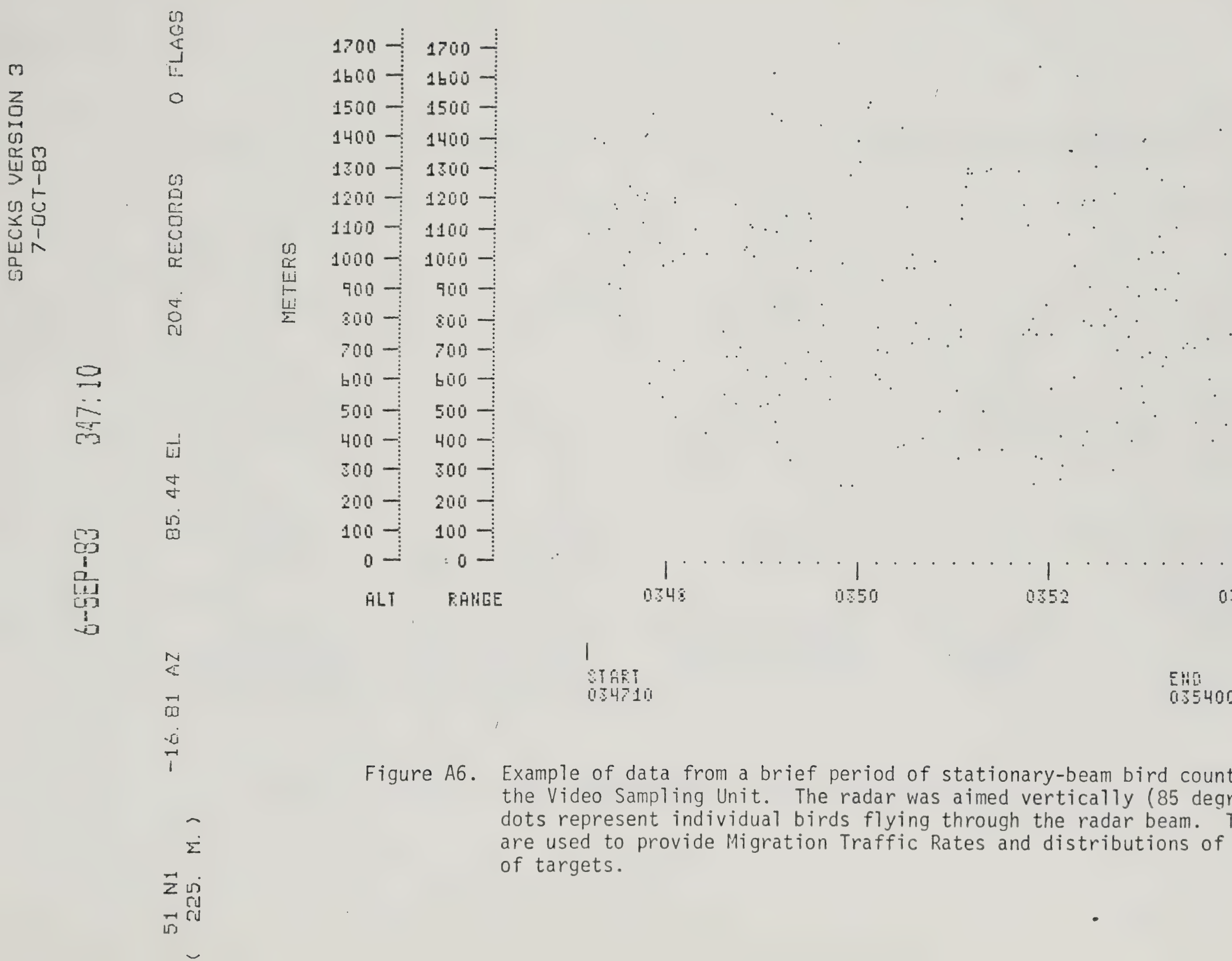

Figure A6. Example of data from a brief period of stationary-beam bird counting using the Video Sampling Unit. The radar was aimed vertically (85 degrees) and dots represent individual birds flying through the radar beam. These data are used to provide Migration Traffic Rates and distributions of altitudes of targets.

Appendix 3

Illinois State Natural History Survey Tracking Radar: Data Reduction Programs

Kind of Data	Data Collection	Editing, Artifact Removal, Formatting	Processing: s/n ratios, coordinate conversion, scaling	Summarization: descriptive statistics and display
Tracks of birds Straightness Levelness Orientation Speed of flight	R	REDIT	V_a transformation WIND8* linear fitting*	CATCH8 RLIST UPPLOT
Migration density				
Stationary-beam counts	V	V1		SPECKS, VLIST, DDD
Ground clutter records	N	NOISV1		PLOTN
Echo characteristics	R			
Target size		REDIT	RANGE*	CATCH8, VSSUM
Target S. D.		REDIT		VSSUM, SDPLOT
Wing Beat Signatures		VSTOVA	FFT**	PLOTV

*Program is being modified and/or improved
**Program not yet written

TO: IIT Research Institute and Cooperators

FROM: Stanley A. Temple, Project Leader and Scott M. Melvin, Research Specialist, Department of Wildlife Ecology, University of Wisconsin, Madison, WI 5370

RE: Progress Report, Research on effects of ELF on bird migration, 17 February-8 June 1983

This report summarizes research conducted by Stanley A. Temple and Scott M. Melvin, Department of Wildlife Ecology, University of Wisconsin-Madison, on the effects of ELF on migrating birds at the Clam Lake ELF Test Facility in the Chequamegon National Forest, Wisconsin.

Preparations for Research, Spring Migration 1983

The period 17 February-14 May was spent planning for spring migration research, and procuring and preparing equipment and supplies for field work. Little preparation could be accomplished prior to late April because of delays and uncertainty in funding. Activities during this period include:

(1) ordering radio-tracking receivers, transmitters, and antennas;

(2) purchasing and reviewing topographic maps of potential study areas near Clam Lake, Wisconsin;

(3) outfitting a tracking vehicle;

(4) obtaining mist netting and banding equipment and miscellaneous field supplies;

(5) obtaining required federal banding permits.

Research, Spring Migration 1983

During 15 May-6 June we conducted field work in the Chequamegon National Forest near the south leg of the ELF antenna (Fig. 1).

Objectives were to: (1) capture and radio-mark migrant thrushes, and monitor their flight paths and subsequent departure bearings over the ELF antennas, (2) evaluate the suitability of our capture, radio-marking, and tracking techniques for studies of effects of ELF on bird migration, and (3) use mist net captures as an index to the volume of migrating birds passing over the ELF antennas.

Birds were captured by a 2-person crew using 5, 6-m and 5, 12-m mist nets, arranged in a roughly east-west line. The forest vegetation at the netting site appeared representative of the surrounding region. Netting effort (Table 1) was calculated in mist net hours; 1 mist net hour equivalent to 1, 6-m net in place for 1 hour.

We captured a total of 15 birds during 603 mist net hours (Tables 1, 2), including 3 hermit thrushes (Catharus guttatus) and 1 veery (Catharus fuscescens). We did not radio-mark the hermit thrushes, believing them to be resident birds that had been present on the study area when we arrived. The veery was thought to be a migrant, and we radio-marked (Raim 1978) and released it on 22 May. It appeared to adjust quickly to its back-mounted radio package, and flew immediately when released. We maintained radio contact with the veery for 9 days and 8 nights. It remained within a localized area of less than .15 mi^2 through at least 30 May. Winds were unfavorable for migration (from the northwest, north, and east) on the nights of 22 May through 30 May. The night of 30 May was completely overcast with rain and winds from the north and east. We did not monitor the radio-marked veery after 2200, assuming that the probability of it migrating under those conditions was low. However, we were unable to re-establish

radio contact with the bird the next morning, 31 May, or on subsequent days. We do not know if the veery actually migrated out of the area or simply made a local movement beyond the range of our searching capabilities, if the radio package fell off, if the radio antenna broke, thereby significantly reducing the range of reception, or if the radio ceased transmitting.

We believe that the large expanse of relatively homogeneous habitat suitable for migrant thrushes that exists in the Chequamegon National Forest was a major factor contributing to our inability to capture larger numbers of migrating thrushes. There are essentially no geographic leading lines or fragmented "islands" of forest habitat to concentrate migrants in the Clam Lake area; thus the probability of encountering large numbers of migrants at a single netting site is low.

During 7-8 June, S. Melvin traveled to the Upper Peninsula of Michigan, to purchase topographic maps and to reconnoiter potential study areas near the site of the proposed ELF antenna. Initial impressions suggested that access to study areas and mobility in radio-tracking migrants would be more difficult in Michigan than at the Clam Lake study site in Wisconsin.

Research Plans, Fall Migration 1983

We intend to shift our mist-netting and radio-tracking studies of migrant birds to the Michigan ELF site during the period of approximately 20 August-15 September 1983, providing a subcontract is issued to the University of Wisconsin-Madison that makes research funds available prior to that period. This will allow us to begin collecting a "control"

set of pre-construction data at the Michigan site, which can be compared to post-construction migration data collected after the Michigan ELF facility has become operational.

We hope to increase our trapping effort by using ground traps in addition to mist nets to capture migrants. We are also exploring the possibility of using migrant thrushes captured at established banding stations along the shore of Lake Michigan, in the Green Bay area, for radio-tracking studies at the Michigan ELF study site.

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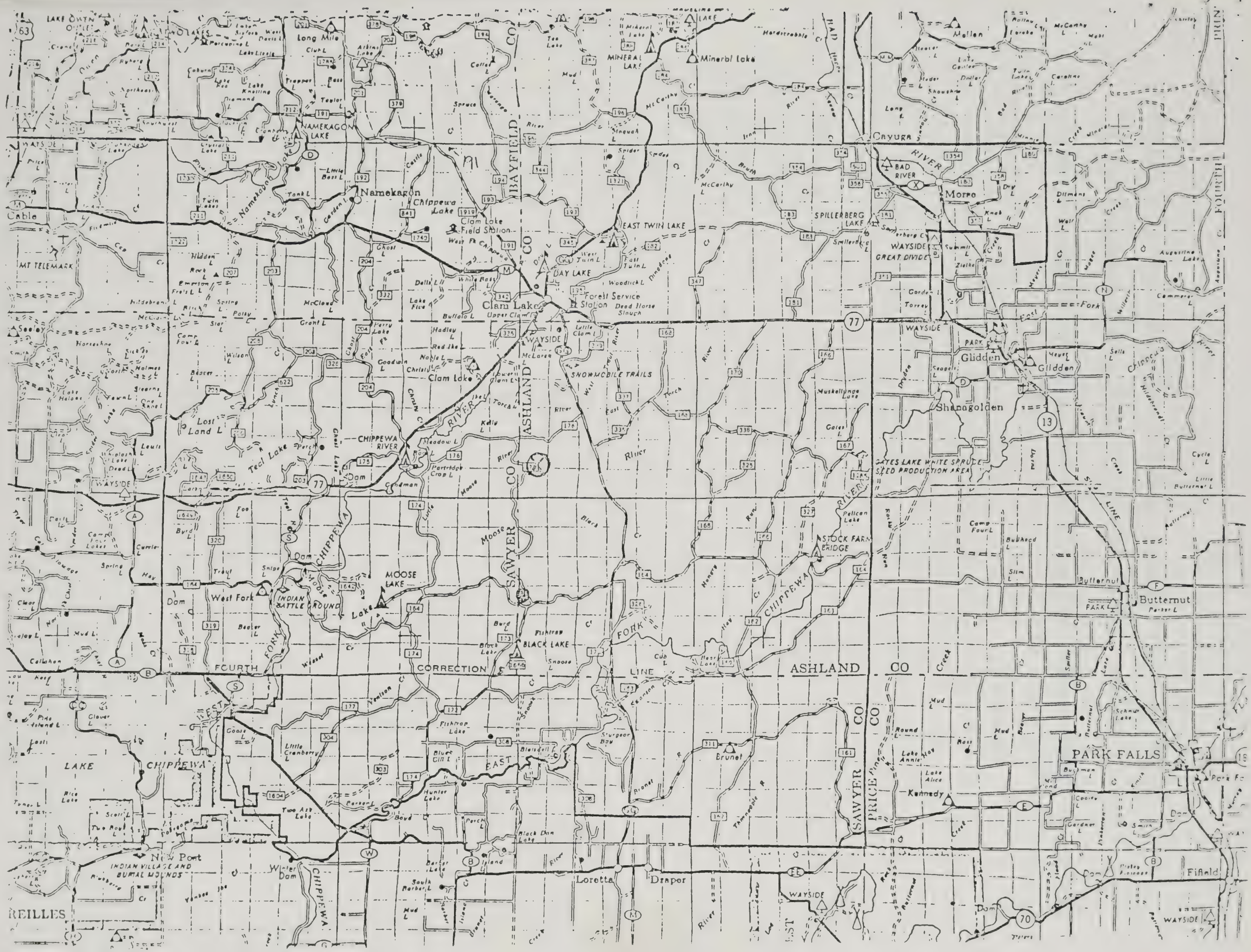
Fig. 1. Location of mist netting site ( ) and ELF transmitter ( ) in the Chequamegon National Forest south of Clam Lake Wisconsin.



Mellen
Cayuga
BAD RIVER
Morse
Namekagon
NAMEKAGON LAKE
Long Mile
Cable
MT TELEMARK
Seeley
Clam Lake
Clam Lake Field Station
Forest Service Station
DAY LAKE
EAST TWIN LAKE
SPILLERBERG LAKE
WAYSIDE
GREAT DIVIDE
Glidden
Shanagolden
GATES LAKE WHITE SPRUCE SEED PRODUCTION AREA
BAYFIELD CO
ASHLAND CO
SAWYER CO
PRICE CO
SNOWMOBILE TRAILS
CHIPPEWA RIVER
MOOSE LAKE
INDIAN BATTLE GROUND
West Fork
BLACK LAKE
STOCK FARM BRIDGE
Butternut
PARK FALLS
Kennedy
Brunet
Loretta
Draper
Fifield
New Port
INDIAN VILLAGE AND BURIAL MOUNDS
Winter Dam
FOURTH
CORRECTION
LINE
REILLES
Mineral Lake
MINERAL LAKE

Table 1. Mist netting effort and success during ELF migration studies in the Chequamegon National Forest, Wisconsin, 18 May-2 June 1983.

Date	Mist net hours	No. of individuals captured
18 May	7.0	0
21 May	57.0	4
22 May	35.0	1
23 May	49.5	1
24 May	33.0	0
25 May	67.5	1
26 May	67.0	2
27 May	60.0	2
28 May	32.0	1
31 May	75.0	3
1 June	60.0	0
2 June	60.0	0
TOTAL	603.0	15

Table 2. Summary of birds captured during ELF migration studies in Chequamegon National Forest, Wisconsin, 18 May-2 June 1983.

Date	Common name	Sex[1]/Age[2]
21 May	Ovenbird	UK/AHY
	Magnolia Warbler	M/AHY
	Nashville Warbler	M/AHY
	Nashville Warbler	M/AHY
22 May	Veery	M/AHY
23 May	Nashville Warbler	M/AHY
25 May	Hermit Thrush	UK/UK
26 May	Ovenbird	UK/AHY
	Ovenbird	UK/AHY
27 May	Yellow-bellied Flycatcher	UK/AHY
	Ovenbird	UK/AHY
28 May	Black-billed Cuckoo	UK/AHY
31 May	Hermit Thrush	UK/AHY
	Hermit Thrush	UK/AHY
	Sharp-shinned Hawk	UK/SY

[1]UK--Unknown, M--Male.

[2]AHY--After Hatching Year, UK--Unknown, SY--Second Year.

Appendix 5. Results of the waterfowl survey conducted during October 1983 at the proposed ELF antenna site (D = kilometers from center of the lake to nearest ELF line).

LAKES CENSUSED

Lake	Township	Sec.	D*	# counted	
Unnamed lake south of Martell's Lake	T 45 N, R 29 W	27	0.21	0	
Unnamed lake east of Pike Lake	T 45 N, R 26 W	21	0.21	0	
Sunsun Lake	T 46 N, R 29 W	35	0.37	0	
Skinnes Lake	T 46 N, R 29 W	25	0.54	0	
Chain of Lakes	T 45 N, R 29 W	28	0.54	0	
Martell's Lake	T 45 N, R 29 W	22	0.70	0	
Birch Lake	T 46 N, R 29 W	11	0.76	0	
Unnamed lake NW of Martell's lake	T 46 N, R 29 W	22	0.81	1	(male mallard)
				1	(female ring-necked duck)
Unnamed lake east of Pike Lake	T 46 N, R 26 W	21	0.92	0	
Charley's Lake	T 46 N, R 26 W	25	0.97	0 **	
Big Perch Lake	T 46 N, R 28 W	34	1.18	0	
Unnamed lake east of Pike lake	T 45 N, R 26 W	28	1.18	0	
Twin Lakes	T 46 N, R 29 W	35	1.40	0	
Long Lake	T 46 N, R 29 W	35	1.50	1	(female ring-necked duck ?)
Crooked Lake	T 45 N, R 26 W	30	1.50	0	
Portersville Lake	T 45 N, R 29 W	28	1.72	1	(species Unknown)
Pike Lake	T 45 N, R 26 W	29	1.72	0 **	
Kidney Lake	T 45 N, R 27 W	33	1.77	0	
Tanglefoot Lake	T 46 N, R 28 W	20	2.21	0 **	
Little Perch Lake	T 45 N, R 28 W	3	2.37	0 **	
Unnamed lake southeast of Helen Lake	T 45 N, R 29 W	10	3.06	0	
Beaver Lake	T 46 N, R 29 W	21	3.70	0	
Perch Lake	T 46 N, R 29 W	8	5.20	0	
Milwaukee Lake	T 46 N, R 29 W	8	5.52	0	
Silver Lake	T 44 N, R 30 W	14	10.47	0 **	